Engineering and Physical Sciences Research Council

CENTRE FOR DOCTORAL TRAINING IN APPLIED PHOTONICS
Use-Inspired Photonic Sensing and Metrology

CDT in Applied Photonics Conference 2024 Abstracts

University of St Andrews · The University of Edinburgh · University of Dundee · University of Glasgow · Heriot Watt University · University of Huddersfield, Inspiring global professionals · NPL National Physical Laboratory · University of Strathclyde Glasgow

Keynote Speaker

Morning Session

Dr Jonathan Silver

Title: Kerr nonlinear optics with microresonators

Abstract:

Ultrahigh-Q optical microresonators have the unique ability to store light for a long time in a very small space, allowing a range of optical nonlinear effects to be observed at input optical powers of milliwatts or even microwatts, and enabling many important new technologies. For example, the generation of frequency combs through the Kerr nonlinearity has potential applications in portable optical clocks, telecoms, radar, lidar, airport security, health monitoring, and astrophysics. In this talk I will present a summary of NPL's work on nonlinear optics with microresonators over the last few years, starting with our discovery of spontaneous symmetry breaking between counterpropagating light in 2016, which led to the realisation of novel optical isolators, memories, logic gates, and gyroscopes, amongst other experimental and theoretical developments. I will then touch upon our demonstration of the first soliton combs in silica microresonators, before moving on to our recent work on self-referenced and integrated microcombs for optical clocks and radar.

Biography:

Jonathan Silver is a Senior Research Scientist at the National Physical Laboratory in Teddington, where he heads a team researching microresonator-based frequency combs, or microcombs. He is currently focusing on developing integrated self-referenced microcombs for portable optical clocks and radar, in collaboration with the Universities of Glasgow, Southampton and Bath. Jonathan joined NPL in 2015 to work with Pascal Del'Haye on optical microresonators and microcombs after completing a PhD in ultracold atoms at the universities of Cambridge and Bonn, Germany. From 2018 to 2020, he held a Royal Academy of Engineering UK Intelligence Community Postdoctoral Research Fellowship hosted by City, University of London, during which time he continued to work at NPL as a Visiting Researcher. He took over the leadership of the team when Pascal moved to Germany in 2019. He grew up in London and holds bachelor's and master's degrees in Natural Sciences from the University of Cambridge.

Keynote Speaker

Afternoon Session

Dr Alison Q. O'Neil

Title: Photons, Foundation Models and Automated Radiological Findings

Abstract:

The recent emergence of powerful deep learning language models trained on huge real world datasets, including multimodal models combining text and image data, has opened up new possibilities for AI in healthcare. Multimodal models enable more sophisticated analysis of images of patients acquired using medical scanners such as X-Ray and Computed Tomography scanners, integrating additional text and clinical data from the patient's record into the machine learning. This talk focusses on the role of AI for radiology, and its potential to assist the radiologist with core expert tasks of detecting and reporting radiological findings.

Biography:

Alison Q. O'Neil is a Principal Scientist in the AI Research Team at Canon Medical Research Europe and is an Honorary Research Fellow at the University of Edinburgh. She received her Engineering Doctorate (EngD) degree from Heriot-Watt University in 2016. Since 2015, she has worked as an industrial research scientist for Canon, and now leads a team working on machine learning for medical imaging and multimodal AI. Alison has 6 patents granted and over 50 technical publications, and has in her turn supervised 4 EngD doctorate students and 5 PhD students. Her interests include robust representation learning, multimodal learning, and the integration of causal techniques with deep learning methods.

First Year Systems Engineering Group Posters

Authors: B. Calder, S. Kutiyal, H. MacKinnon, S. Quinn

Title: MyRIO Marble Maze

Abstract:

The development of an automated robotic marble maze using NI MyRIO, LabView, and other packages. This entails the development of electrical and mechanical systems, actuation and control schemes, automated path planning and computer vision algorithms to develop the components that form the robotic maze.
The system used a digital, single pulse control system driven by 2 stepper motors. Path planning was conducted by an A* greedy algorithm that relies on a morphologically based path segmentation procedure.

Authors: A. Gardner, M. Trabszo, R. Mistry, W. Carter

Title: Laser locking using Wavelength Modulation Spectroscopy

Abstract:

Ultrafast laser-assisted etching provides a new frontier in the fabrication of freeform optics. A volume of fused silica, modified within the focal region of an incident ultrafast laser pulse, is preferentially dissolved within certain chemical etchants. This allows for shapes, of arbitrary form, to be 'written' within the volume of fused silica. These shapes can then be etched out from the fused silica sample, resulting in the fabrication of a free form optic. Several parameters must be optimised in order to have high enough etching rates for minimising form error, including using an SLM to correct for spherical aberrations due to focussing the laser within the volume of the pristine fused silica. This poster will discuss the methods for optimising these parameters, as well as future work towards combining these techniques with CO2 laser polishing for fabricating freeform micro-optics.

Authors: Valeria Pais Malacalza, Zaka Ullah, Shiju Prasad, Dr. Gordon Flockhart

Title: MyRIO Marble MazeInterferometer Stabilisation & Quadrature Locking Using Mixed Analogue Electronics & myRIO Control Loop

Abstract:

The phase stability in an interferometer is of paramount importance for high-precision measurements. Nevertheless, quadrature phase-locking is often disrupted by external disturbances, compromising measurement accuracy. In this study, phase drifts from the quadrature point were addressed applying closed-loop control mechanisms. A hybrid system was implemented with a LabVIEW PI control loop and a reconfigurable input/output (I/O) myRIO device coupled to an external integrator circuit to actively provide feedback to a piezoelectric cylinder to compensate phase drifts and maintain quadrature phase-locking. A fully analogue control loop was built for comparisons. Experimental results revealed that the hybrid control-loop response is enough to compensate for fluctuations under normal lab conditions (e.g. thermal fluctuations), albeit its slow reaction to fast phase fluctuations. A better performance was observed on the analogue control system due to its superior stability and robustness, enabling quadrature phase-locking up to 100 Hz.

Second Year Posters

Authors: A. Clarke, A. Benoît, P. Blair and R. R. Thomson

Title: Optimising Ultrafast Laser-Assisted Etching for Freeform Optics Fabrication

Abstract:
Ultrafast laser-assisted etching provides a new frontier in the fabrication of freeform optics. A volume of fused silica, modified within the focal region of an incident ultrafast laser pulse, is preferentially dissolved within certain chemical etchants. This allows for shapes, of arbitrary form, to be 'written' within the volume of fused silica. These shapes can then be etched out from the fused silica sample, resulting in the fabrication of a free form optic. Several parameters must be optimised in order to have high enough etching rates for minimising form error, including using an SLM to correct for spherical aberrations due to focussing the laser within the volume of the pristine fused silica. This poster will discuss the methods for optimising these parameters, as well as future work towards combining these techniques with CO2 laser polishing for fabricating freeform micro-optics.

Authors: N. Crossley, V. Marques, Y. Chen

Title: Novel DIC methods for optimisation of thermal mechanical simulations of electronics packaged for harsh environments

Abstract:
This project strives to understand to what extent digital image correlation (DIC) can be used to study electronic products and its ability to enhance the accuracy of simulations. The accuracy of the DIC method at temperature will first be evaluated and validated using accepted methods. DIC will then be used to gather the material properties of simple electronic materials which can be fed into simulations of these materials. An inverse analysis process using the real life behavior of electronic materials under thermal load (as measured by DIC) will then be used to improve the accuracy of simulations developed. These simulations can then be further validated by performing real life and simulated accelerated lifetime testing on assemblies studied. The development of highly accurate models of electronic products will improve predictions of the reliability and lifetime in harsh environments and eventually reduce the need for impractical accelerated lifetime testing.

Authors: Kamalpreet Gill, Adam Polak and Michael Lengden

Title: Study of the excitation position in azimuthal photoacoustic resonator

Abstract:
This study optimizes azimuthal resonance modes in a 3D-printed cylindrical resonator to enhance the sensitivity of photoacoustic spectroscopy (PAS) for trace gas detection. The cylindrical resonator, measuring 34 mm in diameter and 50 mm in height, incorporates strategically placed microphones for precise acoustic measurements. By varying the radial position of the excitation source, finite element modelling in COMSOL Multiphysics and experimental validation highlight the critical impact of source positioning on enhancing azimuthal resonance. This adjustment significantly improves resonance characteristics and increases overall sensitivity. Future work involves developing multi-pass optical cells incorporating azimuthal resonant cells and analysing off-axis excitation effects within a multi-spot pattern to refine PAS response. These advancements demonstrate potential for increased PAS sensitivity and accuracy, expanding its application in trace gas detection for environmental monitoring and industrial analysis.

Second Year Posters

Authors: Brendan Hall, Alan Kemp, Ian MacGillivray

Title: Simple Optical Parametric Amplifier for Multiphoton Microscopy

Abstract:
Multiphoton microscopy (MPM) is essential for in vivo brain imaging in cancer and dementia research, using 1300nm and 1700nm wavelengths for deep tissue penetration. These wavelengths are difficult to produce directly through laser emission, so nonlinear frequency conversion with optical parametric amplifiers (OPAs) is used. This project aims to simplify and reduce costs of current systems by using a 1030nm pump laser to generate. Simulations guided the selection of periodically poled lithium niobate (PPLN) parameters. The experimental setup used a multi-grating 5% MgO doped PPLN. Initial results show a 12% conversion efficiency, matching literature, and successful emission at 1700nm. Future work includes direct signal and idler spectra measurement, pulse compression, mode measurement, stability, and OPA optimization.

Authors: E. Martin, M. Lengden, I. Armstrong, P. Black

Title: O2 Detection using High Power Photoacoustic Spectroscopy

Abstract:
Photoacoustic spectroscopy (PAS) provides a method of detecting trace gases with high sensitivity, particularly due to acoustic amplification and direct scaling of laser power to the detected signal. Molecular oxygen remains a challenge for photoacoustic detection due to weak absorption in a narrow band around 760nm, and poor molecular relaxation pathways for the generation of PA signals. This project aims to develop a high-power tapered-amplifier based Master-Oscillator-Power-Amplifier (MOPA) system to boost the power inserted into a photoacoustic cell. A redesign of the photoacoustic cells to account for larger beam diameters is also considered, with minimal impact on the quality of the cell.

Authors: Kieran McGovern, Antoine Borel, Mauro Brotons-Gisbert, Jack Baraclough, Alex Ward, Brian Gerardot

Title: Optical Sensing of Electronic Interactions in Two-Dimensional Semiconductors using a Novel Cryogenic Twisting Device

Abstract:
Twisting layers of 2D materials creates a long-range periodic pattern called a moiré superlattice. This can create flat electronic bands leading to emergent phases of matter including superconductivity and exotic magnetism. The emergent phase diagrams are highly dependent on the moiré period, which is controlled by the relative twist. A hexapod positioner has been designed to tune in situ the relative twist angle between two sheets of atoms in a cryogenic environment, enabling the emergent phases to be characterised by optical spectroscopy or transport.

Second Year Posters

Authors: M. Monaghan, G. Flockhart, C. Michie, G. Bonner

Title: Optical Communications in Challenging Environments

Abstract:
Free space optical communications are emerging as an alternative to radio as the RF spectrum becomes increasingly congested and unavailable. Secure communications at far higher data rates than radio are theoretically possible in the optical domain, however this is achieved at the expense of significant scattering, attenuation and misalignment failures which necessitate advanced beam steering techniques. For communications between aerial platforms such as drones, constraints on the size, weight and power (SWaP) of beam steering systems become prohibitive. Developing beam steering systems which are light, compact and efficient is the key to unlocking optical communications on mobile platforms. We are investigating systems approaches to this problem, considering the lightest possible components which can be used to realise stable communications between aerial platforms.

Authors: Kuo Wang, Mikael Mazur, Martin P.J. Lavery

Title: Enhancing IM-DD MDM FSO Systems Through Deep Learning-Based Turbulence Prediction

Abstract:
A novel deep learning method was introduced for evaluating sequential crosstalk matrices with Intensity Modulation-Direct Detection (IM-DD), designed to predict turbulence intensity and the speed of its fluctuations. This approach facilitates the development of environmentally adaptive free-space communication systems, enhancing link stability in varying conditions.

Third Year Presentations

Authors: I.R Alhamdan, S.A.Schulz

Title: Epsilon Near Zero (ENZ) Metasurfaces for Augmented Reality application

Abstract:
This study showcases multilayered metasurface designs that integrate Indium Tin Oxide (ITO) as an epsilon near zero material (ENZ). The simulation results demonstrate that this structure operates with high efficiency and tunability within the visible spectrum.

Authors: Mohanad Al-Rubaiee, Bocheng Yuan, Yizhe Fan, Simeng Zhu, John Marsh, and Lianping Hou

Title: Semiconductor Mode-Locked Laser Sources for Ultrastable Optical Clocks and High-Speed Optical Communication

Abstract:
In advancing ultrastable optical clocks and high-speed optical communication, we developed passively mode-locked semiconductor lasers at 1.55 μm using AlGaInAs/InP structures. Our 10 GHz laser, with a three-quantum-well active layer, achieved remarkable stability through injection locking, presenting a sub-hertz RF linewidth and below 100 fs timing jitter, making it an ideal optical clock source for enhancing CMOS chip performance. Additionally, our 100 GHz laser, utilizing an asymmetric multiple quantum well (AMQW) active layer, generated a frequency comb with 100 GHz spacing, featuring 14 optical lines within an 11 nm bandwidth, making it highly suitable for high-speed optical communication. This is the widest spectrum achieved by any electrically pumped QW mode-locked laser.

Authors: C. Boland, K. A. Goatman, S. A. Tsaftaris, and S. Dahdouh

Title: There Are No Shortcuts to Anywhere Worth Going: Identifying Shortcuts in Deep Learning Models for Medical Image Analysis

Abstract:
Many studies report human-level accuracy (or better) for AI-powered algorithms performing specific clinical tasks, such as detecting pathology. However, these results often fail to generalise beyond their training distribution. A common cause of this is shortcut learning, where a network erroneously learns to depend on fragile spurious features rather than scrutinising genuinely useful regions of an image. We investigate whether it is possible to detect shortcut learning and locate where the shortcut is happening in a neural network. We propose a novel methodology utilising Prediction Depth and KL divergence to identify the specific layers where shortcut features manifest. We demonstrate that our approach can isolate these layers across several shortcuts, model architectures, and datasets. Using this, we show a correlation between a shortcut's visual complexity, the depth of its manifestation within the model, and its impact on performance. Finally, we highlight the nuanced relationship between learning rate and shortcut learning.

Third Year Presentations

Authors: J. Callaghan, J. Downing, X. Chen

Title: Active Optical Metasurfaces for Solid-State Beam Steering

Abstract:
Active optical metasurfaces are an advanced diffraction-based technology, which use subwavelength structures that can be dynamically tuned in order to arbitrarily control various light properties such as phase, polarisation and wavelength. Where one of the dynamically changing properties is the angle of transmission, an active optical metasurface may serve as a solid-state beam steering device. It is important to carefully assess active materials based on a well-defined figure of merit (FoM), to understand which active material is best suited to the desired function; in this case: beam steering as for time of flight (ToF) and LiDAR.

Authors: P.J. Foley, I.J. Thomson, M.J.D. Esser and A.C. Fleming

Title: Demonstration of Coherent Beam Combination

Abstract:
Coherent Beam Combination (CBC) is a technique that can be employed to overcome the brightness limits of single laser sources by combining multiple sources into a single, robust, near diffraction-limited beam. To unlock the full power scaling potential, careful control of the laser source parameters must be maintained, and tight phase locking between the emitters must be achieved. The work presented here covers a proof of concept and an initial demonstration of low power (10s of mWs) continuous wave CBC system, with three input beams operating at 1064 nm. Implementation of phase control algorithms on relatively low cost microcontrollers is described, with a comparison between conventional state-of-the-art algorithms and a new innovative phase locking technique. A discussion of the next stages is also given, with a view of scaling the laser source power and the number of emitters.

Authors: F.Francis, G.Rowley, A.Harvey and A.D Falco

Title: Fibre coupled on-chip CO2 sensor at 2 um using Slotted Photonic Crystal Waveguide

Abstract:
Environmental and industrial monitoring of trace gases have become ubiquitous for the rapidly advancing digital world. The conventional optical gas sensors use gas cells with large optical pathlength for sensing, making them bulky and heavy for use. In this project, we introduce a unique approach to develop a CO_2 sensor working at 2 µm based on infrared spectroscopy with a footprint of 2 cm x 2 cm. The sensing head of the device includes a Slotted Photonic Crystal Waveguide (SPhCW) – a waveguide geometry with high electric field confinement and slow light which enhances the light-analyte interaction at the slotted region. The device is designed to achieve a group index (ng) of 25 with a bandwidth of 8 nm centred around 2004 nm - the absorption line of CO_2. The devices are fibre coupled using tapered SMF-28 fibres to overcome the mode mismatch.

Third Year Presentations

Authors: A. Keane; P. Murray; J. Zabalza; A. Di Buono; N. Cockbain; R. Bernard

Title: Hyperspectral Imaging has the potential for non-contact salt concentration estimation

Abstract:
Chloride salt accumulation on metals is a precursor to corrosion, with the concentration of salt on a surface posing significant corrosion risks. Traditional methods for measuring salt concentration on metal surfaces involve direct contact techniques, such as swabbing or applying solutions to dislodge the salt. This study investigates the potential of hyperspectral imaging (HSI) as a non-contact method for detecting salt concentration limits. Preliminary results from laboratory experiments are presented, where various concentrations of magnesium chloride ($MgCl_2$) solution were applied to aluminium coupons. Spectral data were collected using a shortwave-infrared (SWIR) hyperspectral sensor (900-2500 nm) after the solutions had dried.

Authors: Cosmin I. Suciu, Marc Sorel, Jonathan SIlver

Title: Platform Development for Frequency Comb Generation Devices

Abstract:
Frequency combs are used in heterodyne detection and dual comb spectroscopy, and are important parts of optical clocks. The project focuses on developing non-linear platforms for fabricating frequency comb microdevices. The presentation provides a fabrication workflow for such devices and covers ongoing work on silicon nitride and titania as the platforms under development.

Authors: S. P. Thompson, B. I. Babu and C. J. Campbell

Title: The Diagnostic Potential of Bile Composition Analysis in Liver Transplantation

Abstract:
The rising prevalence of liver disease has accelerated the demand for liver transplants, surpassing the availability of donors. To expand the donor pool, marginal livers must be utilised despite the associated patient risk. This necessitates an improved method for viability assessment prior to transplantation. Raman spectroscopy offers potential as a quantitative tool for evaluating liver quality, specifically through the analysis of bile. Understanding bile composition provides vital information about liver health. Our initial investigations were hindered by the fluorescence of bile, but the application of surface-enhanced Raman spectroscopy (SERS) enabled the extraction of useful spectral information. SERS substrates were engineered to concentrate specific bile components, which resulted in distinct spectral changes upon their incubation with bile. Principal component analysis identified these key spectral differences. Identifying bile components from their Raman spectral signatures could enhance viability assessments, aiding clinical decisions and increasing the number of livers available for transplant.

Third Year Presentations

Authors: Dorian R Urban, Pavel Novak, Miguel Preciado, Tom Vettenburg

Title: Real-time opto-electronic path-length tuning for optical coherence tomography

Abstract:
Optical Coherence Tomography stands out for its ability to combine the high resolution of microscopy with the penetration-depth of clinical imaging. However, in practice this is still limited to a few millimetres. Interestingly, the imaging-depth of the latest swept-source systems is not limited by their spectral width but by the analog-to-digital sampling rate. In lieu of slow reference arm length adjustments, we leverage opto-electronic frequency shifting. This allows for depth adjustments on the microsecond timescale and a modest detector bandwidth of 200 MHz. The opto-electronic scheme immediately gives us access to an 8 mm range, a fourfold increase over the nominal 2 mm range of the source. Moreover, by circumventing the need for a mechanical reference arm, changes in the axial displacement of the sample can be compensated in real-time. This makes it attractive for imaging arbitrarily curved surfaces. We showcase this with wide-field OCT imaging of the curved retina.